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Growth, nutrient acquisition and physiological responses of papaya (*Carica papaya*) plants to controlled low temperature stress

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ABSTRACT

Study of physiological response of different papaya (*Carica papaya* L.) genotypes to low temperature stress is of paramount importance owing to its higher susceptibility.The present study was conducted under controlled conditions of National Phytotron Facility, ICAR-IARI, New Delhi to investigate the effect of different low temperature regimes on growth, nutrient acquisition and other physiological parameters in five papaya genotypes and one distant relative, i.e. genus *Vasconcellea cundinamarcensis* known for cold tolerance. Results revealed that there was higher reduction in photosynthesis rate, stomatal conductance and transpiration rate under all the low temperature regimes, which leads to reduction of plant growth related parameters. Temperature treated plants showed 57.96% reduction in photosynthetic rate as compared to the control. Amongst the five genotypes, the lowest stomatal conductance was exhibited by *V. cundinamarcensis* (0.026 mol/m^2/s) followed by P-9-5 (0.055 mol/m^2/s). The lowest transpiration rate was also exhibited by *V. cundinamarcensis* (0.39 mol/m^2/s) followed by P-7-9 (0.73 mol/m^2/s). The highest per cent increase in the leaf potassium (K) was observed in genotype *V. cundinamarcensis* (49.15%), followed by P-7-9 (13.29%) while for roots, it was in P-7-9 (128.81%). The genotype *V. cundinamarcensis* also showed the highest mean calcium (Ca) accumulation in both leaf (3.58%) and root (3.67%). Low temperature treatment, in most of the cases, significantly affected the leaf and root nutrient contents, although the level of change was nutrient and genotype specific.

Key words: Low temperature regimes, Nutrient, Papaya Photosynthetic rate, Stomatal conductance, Transpiration rate

Papaya (*Carica papaya* L.), being a tropical plant in nature is severely affected by low temperature. Temperature range of 21° to 33°C is optimum for the growth and development of papaya (Knight 1980). Night temperature below 12° to 14°C for several hours, i.e. during the winter season affects the plant growth and fruit production. The occurrences of frost or sharp fluctuation in temperature in late winter cause severe damage to foliage, crown and flowers resulting negligible yield of poor quality fruit with uneven ripening (Singh *et al*. 2008).

For photosynthetic rate to be optimal, the balance between light absorbed by the photo-systems (PSII and PSI), the transformation of this energy into NADP and ATP, and its utilization in metabolism must constantly be fine-tuned in response to fluctuations in the environment (Ruelland *et al*. 2009). Exposure of plants to low temperature reduces the activity of different enzymes involved in the Calvin cycle and ROS-scavenging systems resulting in ROS generation in PSI and PSII. The change in redox poise imposed by ROS accumulation, resulted in reduction of photosynthetic rate and hampered the other physiological process of plants (Yun *et al*. 2010).

Almost all the commercial varieties of *C. papaya* are highly sensitive to low temperature stress. Though the distant relatives of cultivated papaya *viz*. *Vasconcellea cundinamarcensis*, *V. pennata* and *V. pentagona* are resistant to frost but none have been evaluated systematically for physiological responses under the low temperature stress (Ram 2005). The aim of the present research was to study the nutrient acquisition, physiological response and growth related changes in papaya genotypes under low temperature stress and to recognize any cold tolerance papaya genotype based on their performance.

MATERIALS AND METHODS

Plant material for the experiment included five *C. papaya* genotypes (Red Lady, Pusa Nanha, P-7-15, P-7-9 and P-9-5) and one cold tolerant genotype (*Vasconcellea cundinamarcensis*). Evaluation for low temperature stress was undertaken at the controlled environment conditions in

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the growth chambers maintained at the National Phytotron Facility, ICAR-IARI, New Delhi during 2016-17. The seeds of above mentioned genotypes were sown in the trays containing the growing medium comprising of perlite, vermiculite, coco peat and vermicompost (1:1:1:1) and then transplanting done at eight week after sowing, into plastic pots filled with same potting medium and maintained under the growth chamber. All other recommended standard operations were performed at proper stage of the plants. A temperature regime of 28/18ºC (day/night) along with a photoperiod of 12 h 30 min. (L/D) and relative humidity of 70±5% during day and 85-90% during the night and irradiance of 700-800 µmol/m^2/s at leaf level. After proper establishment of the transplanted seedlings, the temperature treatments were induced by lowering the temperature in the growing chamber by 2ºC per two day from 26/16ºC (day/night) to 20/10ºC (day/night) up to 8 days. In total, three replications comprising of 9 plants per replication for each genotype were maintained. In control (T_0), three plants for each genotype were maintained at 28/18ºC (day/night) regime. The details of temperature treatments are given in Table 1.

Plant height (cm) of papaya plants was measured from the collar region to the base of the last fully opened leaf on the main stem with the help of measuring scale, while the stem diameter (mm) was measured at the base of the stem with Digimatic Vernier calipers. Both these observations were recorded at the starting day (before any treatment) and eighth day (after T_4 for treated plants and for control plants without temperature treatment) of low temperature treatments. The per cent change in final observation over the initial was calculated for both control and treated plants. The root length (cm) was recorded at the termination of the experiment for both the control and the treated (*i.e.* after the fourth treatment) plants.

Leaf gas exchange traits such as internal CO_2 concentration (*Ci*), transpiration rate (*E*), stomatal conductance (g_s), and photosynthetic rate (*A*) were measured on four mature leaves for each replication using LCi-SD Ultra Compact Photosynthesis System after induction of each treatment.

Tissue (both leaves and roots) nutrient analysis was done at the termination of the experiment for both the control and the treated (i.e. after the fourth treatment) plants. Nitrogen (N) content in the samples was determined by using Digestion Block method outlined by Bremner *et al.* (1965) and phosphorus (P) by vanado-molybdo-phosphoric yellow colour method (Jackson 1973) while total potassium (K) and sodium (Na) content was estimated from diacid digested plant samples using a microprocessor based flame photometer according to the method given by Jackson (1980). Calcium (Ca) and magnesium (Mg) content were ascertained by atomic absorption spectrophotometer according to Jackson (1980).

The statistical analysis of the data which comprised of three replications were analysed in factorial completely randomized block design using statistical analysis system software, SAS package (9.3 SAS Institute, Inc, and USA) followed by t-tests (LSD). P values ≤ 0.05 were considered as significant.

Table 1 Details of controlled temperature regimes maintained under growth chamber.

Treatment	Day temperature (ºC)	Night temperature (ºC)
T_0 (control)	28±0.1	18±0.1
T_1	26±0.1	16±0.1
T_2	24±0.1	14±0.1
T_3	22±0.1	12±0.1
T_4	20±0.1	10±0.1

Table 2 Effect of different temperature regimes on per cent change in plant height (cm) of papaya genotypes grown under controlled phytotron conditions

Genotype	Initial plant height (cm)			Final plant height (cm)			% Change	
	T_0	T_4	Mean	T_0	T_4	Mean	T_0	T_4
Red Lady	15.63^{bcd}	15.33^{bcd}	15.48^{b}	16.97^{cde}	16.39cdef	16.68b	8.53	6.92
Pusa Nanha	14.03^{cde}	15.28^{bcd}	14.66^{b}	16.07def	16.79cde	16.43b	14.49	9.86
P-7-15	26.90^{a}	21.65^{ab}	24.28^{a}	29.13ab	23.34bc	26.24a	8.30	7.79
P-7-9	17.67^{bc}	17.52^{bc}	17.59^{b}	20.30cd	19.27cd	19.78b	14.91	9.97
P-9-5	28.40^{a}	26.31^{a}	27.35^{a}	30.67a	27.98ab	29.32a	7.98	6.36
V. c.	8.07^{e}	9.05^{e}	8.56^{c}	9.53f	10.03ef	9.79c	18.18	10.84
Mean	18.45^{a}	17.52^{a}		20.44a	18.97a			
LSD (P ≤ 0.05)								
Genotype (G)			4.90			5.05		
Temperature (T)			NS			NS		
G × T			NS			NS		

Temperature regime: Initial T_0 - 28°C (day) and 18°C (night); Initial T_4 – 28°C (day) and 18°C (night); Final T_0 - 28°C (day) and 18°C (night); Final T_4- 20°C (day) and 10°C (night); *V. c.- Vasconcellea cundinamarcensis*

RESULTS AND DISCUSSION

A perusal of data (Table 2) indicated the non-significant effect of low temperature treatment (T) and G × T interactions on both initial and final plant height, while the genotype (G) significantly influenced plant height. In all the genotypes, the per cent change in control plants were higher than the treated plants. The highest per cent change for both control (18.18%) and treated plants (10.84%) was observed in the *V. cundinamarcensis*, which indicates the stable growth rate even under the exposed low temperature regimes. The effect of temperature on the stem diameter was statistically non-significant (Table 3). Amongst the control, the highest per cent change in stem diameter was found in Red Lady (4.29%), while for treated plants in P-9-5 (2.00%). Our results are in agreement with those of Barros *et al.* (1997), who observed decline in the vegetative growth of *Coffea arabica* L. under the low temperature regimes. The occurrences of frost or sharp fluctuation in temperature in late winter cause severe damage to foliage, crown and flowers resulting negligible yield of poor quality fruit with uneven ripening in papaya (Singh *et al*., 2008).

The seedling root length was significantly influenced by low temperature regime, papaya genotype and their interaction (Table 4). The results showed an increase in root length under the low temperature stress conditions. The root length of treated plants (6.45 cm) was significantly higher than the control (6.29 cm). The highest mean root length (7.05 cm) was observed in both genotype *V. cundinamarcensis* and P-9-5. From the possible interaction values, the treated plants of *V. cundinamarcensis* (7.20 cm) were having the longest roots.

Temperature (T), genotype (G) and G×T interaction significantly affected all the leaf gas exchanging parameters. Exposure to low temperature regimes lead to reduction in the leaf gas exchanging parameters. Temperature treated plants showed lower photosynthetic rate (*A*) value than the control plants and the T_4 (1.05 μmol/m^2/s) plants exhibited 57.96% reduction as compared to the control (T_0) plants (2.51 μmol/m^2/s) (Fig 1a). Amongst the genotypes, P-7-15 exhibited the highest mean *A* (2.05 μmol/m^2/s). As compared to the control, the highest per cent decrease in the *A* at T_4, was observed in Red Lady (82.10%), while the lowest in P-7-9 (24.26%). It was reported that low temperatures affect different aspects of photosynthesis process (Ruelland *et al*. 2009). In the present study, exposure to low temperature stress leads to photostasis imbalance resulting in reduction in photosynthesis rate. Similar results in papaya was reported by Grau *et al.* (1997) who observed a 15% reduction in photosynthesis rate at low temperature regime (15º day/

Table 4 Effect of different temperature regimes on root length (cm) of papaya genotypes under controlled phytotron conditions

Genotype	Root length (cm)		
	Control	Treatment	Mean
Red Lady	5.60^{e}	5.52^{e}	5.56^{d}
Pusa Nanha	6.37^{b}	6.48^{b}	6.42^{b}
P-7-15	5.77^{de}	5.97^{cd}	5.87^{c}
P-7-9	6.20^{bc}	6.39^{b}	6.30^{b}
P-9-5	6.93^{a}	7.16^{a}	7.05^{a}
V. c.	6.90^{a}	7.20^{a}	7.05^{a}
Mean	6.29^{b}	6.45^{a}	
LSD (P ≤ 0.05)			
Genotype (G)			0.23
Temperature (T)			0.13
G × T			0.32

Temperature regime: Control - 28°C (day) and 18°C (night); Treatment - 20°C (day) and 10°C (night); *V. c.- Vasconcellea cundinamarcensis*

Table 3 Effect of different temperature regimes on per cent change in stem diameter of papaya genotypes grown under controlled phytotron conditions

Genotype	Initial stem diameter (mm)			Final stem diameter (mm)			% Change	
	T_0	T_4	Mean	T_0	T_4	Mean	T_0	T_4
Red Lady	3.50^{d}	4.16^{cd}	3.83^{c}	3.65^{d}	4.24^{cd}	3.94^{c}	4.29	1.87
Pusa Nanha	5.33^{bc}	5.19^{bc}	5.26^{b}	5.45^{bc}	5.28^{bcd}	5.36^{b}	2.26	1.71
P-7-15	5.50^{bc}	5.18^{bc}	5.34^{b}	5.65^{bc}	5.26^{bcd}	5.46^{b}	2.66	1.69
P-7-9	7.16^{a}	5.31^{bc}	6.23^{ab}	7.31^{a}	5.39^{bc}	6.35^{ab}	2.10	1.63
P-9-5	6.58^{ab}	6.57^{ab}	6.57^{a}	6.75^{ab}	6.70^{ab}	6.72^{a}	2.58	2.00
V. c.	6.79^{ab}	7.85^{a}	7.32a	6.90^{ab}	7.96^{a}	7.43^{a}	1.62	1.32
Mean	5.81^{a}	5.71^{a}		5.95^{a}	5.81^{a}			
LSD (P ≤ 0.05)								
Genotype (G)			1.16			1.16		
Temperature (T)			NS			NS		
G × T			1.64			1.64		

Temperature regime: Initial T_0 - 28°C (day) and 18°C (night); Initial T_4 – 28°C (day) and 18°C (night); Final T_0 - 28°C (day) and 18°C (night); Final T_4-20°C (day) and 10°C (night) *V. c.- Vassconcellea cundinamarcensis*

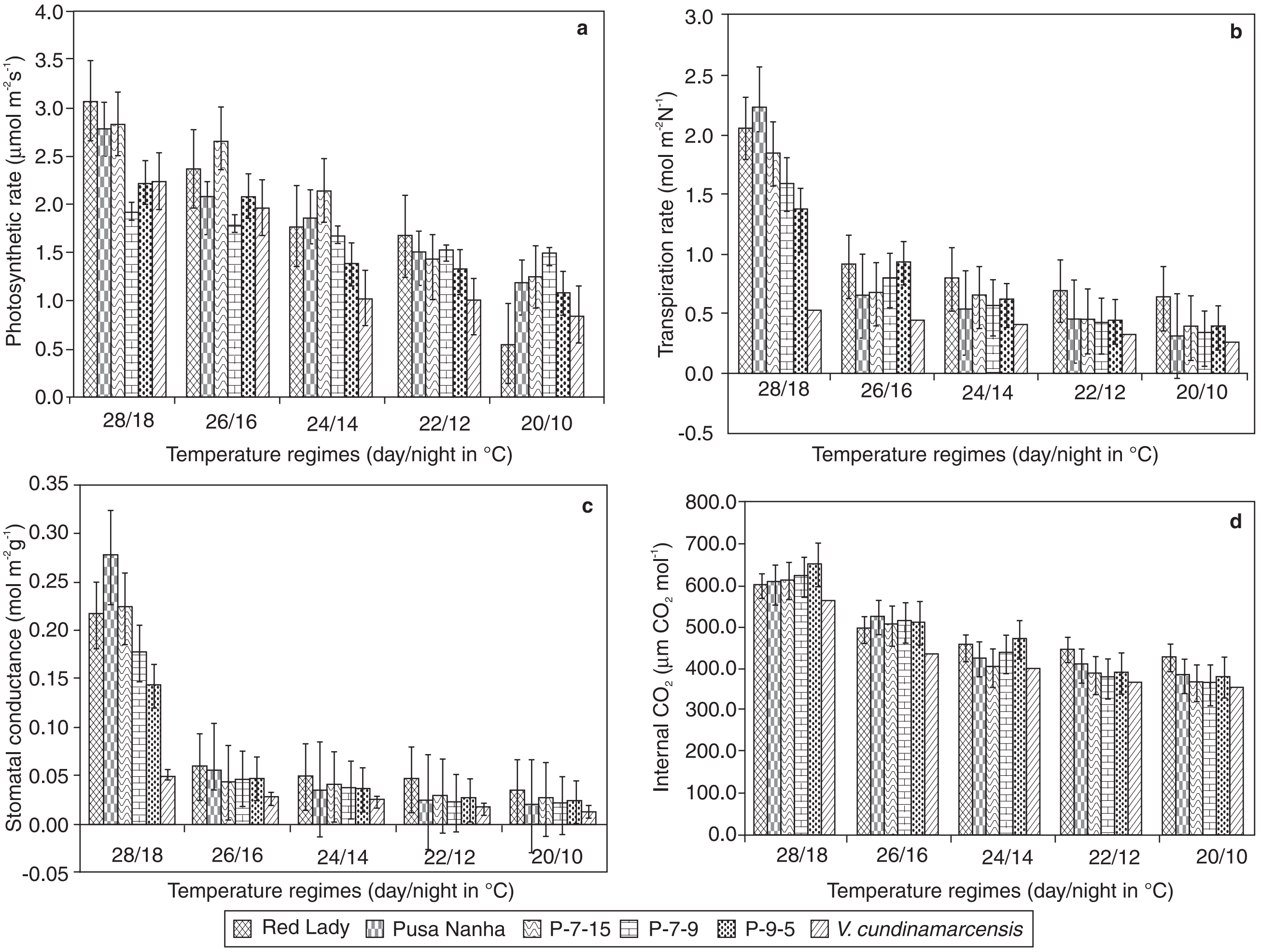

Fig 1 Effect of different temperature regimes on leaf gas exchange parameters of papaya genotypes grown under controlled phytotron conditions. a: Photosynthesis rate; b: Transpiration rate; c: Stomatal conductance; d: Internal CO_2 concentration. Vertical bars indicate ± SE mean.

5ºC night; 4 days) as compared to the control (25º day/15ºC night).

The T_4 plants (0.38 mol/m^2/s) exhibited 76.35% reduction in *E* as compared the control (1.60 mol/m^2/s) (Fig 1b). Amongst the genotypes, the lowest mean *E* was observed in *V. cundinamarcensis* (0.39 mol/m^2/s), while amongst the G×T interactions, the lowest *E* (0.26 mol/m^2/s) was maintained by the *V. cundinamarcensis* × T_4. This reduction in the transpiration rate may be due to reduced moisture loss under the low temperature stress. Generally, plant genotypes that tolerate low temperature stress are able to maintain high leaf water potential by closing their stomata and preventing transpirational water loss (Wilkinson *et al*. 2001). Exhibition of lower transpiration rate by *V. cundinamarcensis* showed its tolerance capacity to low temperature stress.

The *Ci* was reduced significantly under the decreasing temperature regimes and T_4 (378.11 µmol CO_2/mol) plants experienced a 37.92% as compared to the T_0 (609.11 µmol CO_2/mol) (Fig 1d). Amongst the genotypes, *V. cundinamarcensis* was had the lowest *Ci* (422.47µmol CO_2 mol^{-1}). *V. cundinamarcensis* × T_4 (350.67 µmol CO_2/mol) registered the lowest *Ci* amongst all possible G × T interactions. Low temperature stress tended to suppress the *Ci* (from T_0 to T_4) within the genotypes too, and showed the highest reduction in P-9-5 (41.68%).

Temperature treatment highly reduced the g_s and the T_4 plants (0.024 mol/m^2/s) exhibited 87.42% reduction in the g_s as compared to the T_0 plants (0.181 mol/m^2/s) (Fig 1c). Amongst the genotypes, the lowest g_s was exhibited by *V. cundinamarcensis* (0.026 mol/m^2/s). Amongst all the possible G × T interactions, the lowest g_s was observed in genotype *V. cundinamarcensis* × T_4 (0.013 mol/m^2/s). Our results agree with the findings of Grau *et al.* (1997) and Barros *et al.* (1997). Clemente and Marler (1996) also reported that photosynthetic response of papaya was strongly linked to environmental conditions through stomatal behaviour. Jeyakumar *et al.* (2005) reported that leaf relative water content had significant influence on photosynthesis by reducing the photosynthetic rate under abiotic stress. In the present study, similar result trends of were noted, in which the highest reduction in both the photosynthetic rate and leaf relative water (data not presented) content were observed in genotype Red Lady, owing to its higher susceptibility to low temperature.

Low temperature treatment, in most of the cases, significantly affected the leaf and root nutrient contents, although the level of change was nutrient and genotype specific. The highest accumulation of leaf N was estimated in *V. cundinamarcensis* (2.90%), while leaf P was in P-7-15 (0.64%) (Table 5). Although the highest leaf K content was observed in Pusa Nanha (5.27%) but *V. cundinamarcensis* exhibited the highest per cent change (49.15%) after low temperature exposure. The highest per cent increase change in the leaf Ca content was observed in genotype P-9-5 (17.75%), while leaf Na content in *V. cundinamarcensis* (180.00%) (Table 6). Leaf Mg content declined after temperature treatment and the lowest decline was observed in P-9-5 (11.75%) followed by *V. cundinamarcensis* (16.92%). Amongst the root nutrients content, the highest per cent change increase in N content was observed in the genotype P-9-5 (32.08%), while P (268.88%) and K (128.81%) in P-7-9 (Table 7). The highest mean root Ca content was observed in the genotype *V. cundinamarcensis* (3.67%), while Mg in P-9-5 (0.98%) and Na in Red Lady (2.68%) (Table 8). Na content showed both the increasing and decreasing trends in leaf and root in the present study. However, it was highly reduced in both leaf (30.00%) and root (56.95%) of the genotype Red Lady. Waraich *et al*. (2012) reported that among the nutrients, potassium (K) and calcium (Ca) played a major role in elevating the chilling stress. Potassium can provide protection against oxidative damage caused by

Table 5 Effect of different temperature regimes on leaf macro nutrient content (N, P and K) of papaya genotypes grown under controlled phytotron conditions

Genotype	N (%)				P (%)				K (%)			
	Control	Treatment	Mean	% Change	Control	Treatment	Mean	% Change	Control	Treatment	Mean	% Change
Red Lady	1.71^{def}	1.96^{cde}	1.84^{c}	15.04	0.58^{bcde}	0.48^{ef}	0.53^{bc}	-16.67	5.29^{ab}	4.22^{bcd}	4.75^{ab}	-20.29
Pusa Nanha	1.77^{cde}	2.24^{bc}	2.00^{c}	26.60	0.64^{abc}	0.57^{bcde}	0.60^{ab}	-10.87	5.71^{a}	4.83^{abc}	5.27^{a}	-15.46
P-7-15	1.49^{ef}	1.21^{f}	1.35^{d}	-18.75	0.60^{bcd}	0.68^{ab}	0.64^{a}	12.11	5.08^{ab}	4.87^{abc}	4.98^{a}	-4.01
P-7-9	2.25^{bc}	2.62^{ab}	2.44^{b}	16.44	0.52^{cdef}	0.74^{a}	0.63^{a}	40.27	4.11^{bcd}	4.66^{abc}	4.39^{ab}	13.29
P-9-5	1.69^{def}	2.10^{bcd}	1.90^{c}	24.70	0.52^{def}	0.30^{g}	0.41^{d}	-40.97	4.59^{abc}	3.12^{d}	3.86^{b}	-32.15
V. c.	2.79^{a}	3.01^{a}	2.90^{a}	7.89	0.42^{fg}	0.50^{def}	0.46^{cd}	18.42	3.74^{cd}	5.57^{a}	4.66^{ab}	49.15
Mean	1.95^{b}	2.19^{a}			0.55^{a}	0.54^{a}			4.75^{a}	4.55^{a}		
LSD ($P \leq 0.05$)												
Genotype (G)			0.36				NS					NS
Temperature (T)			0.21				0.05					0.54
G × T			0.52				0.12					1.31

Temperature regime: Control - 28°C (day) and 18°C (night); Treatment - 20°C (day) and 10°C (night); *V. c.*- *Vasconcellea cundinamarcensis*}. –ve sign shows a decline in nutrient content.

Table 6 Effect of different temperature regimes on leaf nutrient content (Ca, Mg and Na) of papaya genotypes grown under controlled phytotron conditions

Genotype	Ca (%)				Mg (%)				Na (%)			
	Control	Treatment	Mean	% Change	Control	Treatment	Mean	% Change	Control	Treatment	Mean	% Change
Red Lady	1.69^{f}	1.53^{f}	1.61^{d}	-9.66	0.58^{cdef}	0.41^{f}	0.49^{b}	-29.89	0.30^{a}	0.21^{b}	0.26^{a}	-30.00
Pusa Nanha	1.81^{f}	2.07^{ef}	1.94^{d}	14.34	0.71^{cdef}	0.50^{ef}	0.60^{b}	-29.72	0.21^{b}	0.19^{b}	0.20^{ab}	-9.52
P-7-15	2.61^{cde}	2.46^{de}	2.54^{c}	-5.99	0.84^{bcd}	0.57^{cdef}	0.71^{b}	-31.75	0.13^{bcde}	0.21^{b}	0.17^{b}	61.54
P-7-9	3.08^{bc}	2.88^{cd}	2.98^{b}	-6.28	0.81^{bcde}	0.57^{def}	0.69^{b}	-29.34	0.17^{bc}	0.18^{bc}	0.18^{b}	5.88
P-9-5	2.67^{cd}	3.14^{bc}	2.90^{bc}	17.75	1.22^{a}	1.08^{ab}	1.15^{a}	-11.75	0.10^{cde}	0.08^{de}	0.09^{c}	-20.00
V. c.	3.46^{ab}	3.71^{a}	3.58^{a}	7.13	1.08^{ab}	0.90^{abc}	0.99^{a}	-16.92	0.05^{e}	0.14^{bcd}	0.10^{c}	180.00
Mean	2.55^{a}	2.63^{a}			0.87^{a}	0.67^{b}			0.16^{a}	0.17^{a}		
LSD ($P \leq 0.05$)												
Genotype (G)			NS				0.23					NS
Temperature (T)			0.23				0.13					0.04
G × T			0.56				0.33					0.09

{Temperature regime: Control - 28°C (day) and 18°C (night); Treatment - 20°C (day) and 10°C (night); *V. c.*- *Vasconcellea cundinamarcensis*}. –ve sign shows a decline in nutrient content.

Table 7 Effect of different temperature regimes on root nutrient content (N, P & K) of papaya genotypes grown under controlled phytotron conditions

Genotype	N (%)				P (%)				K (%)			
	Control	Treat-ment	Mean	% Change	Control	Treat-ment	Mean	% Change	Control	Treat-ment	Mean	% Change
Red Lady	1.99^{ef}	2.13^{def}	2.06^{c}	7.05	0.71^{b}	0.79^{ab}	0.75^{ab}	12.46	5.56^{cde}	7.21^{ab}	6.38^{ab}	29.62
Pusa Nanha	1.88^{gf}	2.10^{def}	1.99^{c}	11.68	0.85^{a}	0.82^{ab}	0.83^{a}	-4.34	5.99^{bcd}	6.30^{abc}	6.15^{bc}	5.18
P-7-15	1.81^{gf}	1.46^{g}	1.64^{d}	-19.00	0.79^{ab}	0.76^{ab}	0.78^{ab}	-3.41	7.30^{a}	7.11^{ab}	7.20^{a}	-2.65
P-7-9	2.48^{bcd}	2.71^{abc}	2.60^{b}	9.27	0.20^{d}	0.72^{b}	0.46^{c}	268.88	2.01^{g}	4.61^{def}	3.31^{e}	128.81
P-9-5	1.77^{gf}	2.33^{cde}	2.05^{c}	32.08	0.70^{b}	0.77^{ab}	0.74^{b}	10.60	5.59^{cde}	5.07^{def}	5.33^{cd}	-9.31
V. c.	2.83^{ab}	3.09^{a}	2.96^{a}	9.43	0.42^{c}	0.22^{d}	0.32^{d}	-46.65	5.27^{cdef}	4.26^{f}	4.77^{d}	-19.22
Mean	2.13^{a}	2.31^{b}			0.61^{a}	0.68^{b}			5.29^{a}	5.76^{a}		
LSD ($P \leq 0.05$)												
Genotype (G)			0.31				0.09				NS	
Temperature (T)			0.18				0.05				0.50	
G × T			0.43				0.12				1.23	

Temperature regime: Control - 28°C (day) and 18°C (night); Treatment - 20°C (day) and 10°C (night); *V. c.- Vasconcellea cundinamarcensis*}. –ve sign shows a decline in nutrient content.

Table 8 Effect of different temperature regimes on root nutrient content (Ca, Mg & Na) of papaya genotypes grown under controlled phytotron conditions

Genotype	Ca (%)				Mg (%)				Na (%)			
	Control	Treat-ment	Mean	% Change	Control	Treat-ment	Mean	% Change	Control	Treat-ment	Mean	% Change
Red Lady	1.56^{g}	1.92^{gf}	1.74^{c}	23.03	0.57^{cd}	0.40^{d}	0.49^{c}	-30.23	3.74^{a}	1.61^{cde}	2.68^{a}	-56.95
Pusa Nanha	1.66^{g}	2.12^{efg}	1.89 ^{c}	27.25	0.74^{bc}	0.67^{bcd}	0.70^{bc}	-9.91	2.39^{b}	1.57^{de}	1.98^{bc}	-34.31
P-7-15	2.66^{cde}	2.67^{cde}	2.66^{b}	0.38	0.74^{bc}	0.62^{bcd}	0.68^{bc}	-16.59	1.35^{ef}	1.74^{bcde}	1.55^{cd}	28.89
P-7-9	2.58^{def}	2.96^{bcd}	2.77^{b}	14.71	0.64^{bcd}	0.56^{cd}	0.60^{c}	-13.47	0.55^{g}	1.58^{cde}	1.07^{de}	187.27
P-9-5	2.84^{bcd}	3.34^{abc}	3.09^{b}	17.58	1.10^{a}	0.86^{abc}	0.98^{a}	-21.52	2.27^{bc}	2.19^{bcd}	2.23^{ab}	-3.52
V. c.	3.52^{ab}	3.81^{a}	3.67^{a}	8.33	0.90^{ab}	0.75^{bc}	0.83^{ab}	-16.97	1.19^{efg}	0.74^{fg}	0.97^{e}	-37.82
Mean	2.47^{b}	2.80^{a}		13.46	0.78^{a}	0.64^{b}			1.92^{a}	1.57^{b}		
LSD ($P \leq 0.05$)												
Genotype (G)			0.50				0.22					0.49
Temperature (T)			0.29				0.13					0.28
G × T			0.71				0.31					0.70

Temperature regime: Control - 28°C (day) and 18°C (night); Treatment - 20°C (day) and 10°C (night) *V. c.- Vasconcellea cundinamarcensis* }. –ve sign shows a decline in nutrient.

chilling or frost, thus reducing the formation of reactive oxygen species. K also played a major role in stomata closure and thus reduction of transpiration loss under the cold stress (Wilkinson *et al*., 2001). In the present study also, the increase in K content and decline in stomatal conductance and transpiration rate was observed. Grewal and Singh (1980) and Hakerlerler *et al.* (1997) reported that external application of K fertilizer could alleviate the effect of chilling temperature. Gagnon *et al.* (1990) correlated cold hardiness with percent dry weight and accumulation of total nitrogen in roots of strawberry Liana.

Calcium has been shown to be an essential requirement for chilling induced stomatal closure in chilling tolerant genotypes (Wilkinson *et al.* 2001). In the present study, amongst the six genotypes evaluated, *V. cundinamarcensis* showed the highest mean Ca accumulation in both leaf (3.58%) and root (3.67%). The higher leaf chlorophyll content (not given here) of genotype P-9-5 can be correlated to the lower reduction in leaf Mg content following the exposure to low temperature regimes as Mg is an essential part of leaf chlorophyll.

From the experiment results, it can be concluded that exposure of papaya genotypes to low temperature stress resulted in reduction of plant growth, which may be due to lowered photosynthetic rate. Moreover, higher potassium and calcium contents may have reduced the stomatal conductance and transpiration rate to reduce the water loss. Based on the results, the genotypes P-9-5 and P-7-9 can be regarded as tolerant to low temperature stress, compared to the cold tolerant wild genotype (*Vasconcellea cundinamarcensis*).

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